Historical and Current Habitat Conditions Analysis for the Upper Green River Subwatershed

June 2004

GREEN/DUWAMISH AND CENTRAL PUGET SOUND WATERSHED

WRIA
Steering Committee

and

King County
Department of Natural Resources and Parks
Water and Land Resources Division
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Historical and Current Habitat Conditions Analysis for the Upper Green River Subwatershed

Prepared for:

Water Resources Inventory Area (WRIA) 9 Strategic Assessment

Submitted by:

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Watershed Coordination Services provided by
King County Water and Land Resources Division
Department of Natural Resources and Parks

Funded in part by the King Conservation District

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EXECUTIVE SUMMARY

The objective of this study was to assess the quantity and location of historical and current salmonid habitat in the Upper Green River subwatershed, and the processes that create those conditions, in order to support protection and restoration efforts for salmon conservation and recovery. The historical conditions assessment focuses on physical channel characteristics in the Upper Green mainstem river around 1901 to 1910-11. Mid-century conditions were documented using aerial photography interpretation from 1964 and the current conditions assessment was based primarily on aerial photography 1998. In addition, aerial photographs from 1959 were used to assess habitat conditions in the section of channel now inundated by Howard Hanson dam. The mainstem river was stratified into reaches based largely on channel morphology in order to facilitate this assessment.

The Upper Green River subwatershed is the area upstream of Howard Hanson dam, beginning at Rivermile (RM) 64.4. The headwaters of the Green River begin on the western crest of the Cascade Mountains, near RM 93.6, at an elevation over 1,500 m (5,000 feet). The basin encompasses 60,700 hectares with approximately 7,735 km of mapped stream channels, including an estimated 267 km of fish-bearing streams. Major tributaries include the North Fork Green River, Smay Creek, Charley Creek, Champion Creek, Sawmill Creek, Tacoma Creek, Twin Camp Creek, and Sunday Creek.

Large-scale fires affected much of the upper basin in the early 1300s, 1500s, and 1700s. Riparian areas typically would not have burned as frequently or as intensely as the rest of the watershed (USFS 1996), leaving more mature timber within the riparian area.

Historically, forest stands consisted of dense coniferous forests (USFS 1996). Riparian species were noted in the General Land Office surveys as consisting of alder, cedar, hemlock and maple, with the largest size trees ranging from 90-180 cm in diameter (Brown 1891). Mainstem channel widths (RM 64.5 to 85) measured from 1901 and 1910/11 USGS topographic maps ranged from 36 to 74 meters. Pool quantities were estimated based upon geomorphic spacing for pools of one pool for every 5 to 7 channel widths (Leopold et al. 1964). Large woody debris was estimated based upon studies in unmanaged forest streams in western Washington and Alaska. For streams similar in size to the upper Green River, these studies found a range of 240 to 2,080 pieces of large woody debris per kilometer.

The current forest conditions are primarily seedling/shrub and immature forest stands (USFS 1996). Much of the riparian corridor along the mainstem Green River was harvested or burned in fires around the turn of the century. The present riparian conditions are predominantly small to medium-sized deciduous or mixed deciduous and coniferous stands with less than 1% of the riparian zone in pure coniferous stands (Kerwin and Nelson 2000). The area immediately surrounding Howard Hanson reservoir is bare ground due to seasonal inundation. Mainstem channel widths range from 30 to 140 meters and the river has a sinuous pattern through most reaches. Habitat inventories identified pool spacing ranging from 3 to 16 channel widths, although these inventories covered only a relatively small portion (<20%) of the mainstem river between RM 64.5 to 85. Recent surveys found a range of 4.5 pieces of large wood (>30.5 cm diameter and 9.1 meters long) per kilometer to 68 pieces of large wood (>10 cm diameter and 1 meter long). Forest roads have substantially increased the amount of sediment contributed to streams in the Upper Green River subwatershed.

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INTRODUCTION

The objective of this study was to assess the quantity and location of historical and current salmonid habitat in the Upper Green River subwatershed, and the processes that create those conditions, in order to support protection and restoration efforts for salmon conservation and recovery. This report describes the historical and current channel conditions in the Upper Green River above Howard Hanson dam. The historical conditions assessment focuses on physical channel characteristics in the Upper Green mainstem river around 1901 to 1910-11. Mid-century conditions were documented using aerial photography interpretation from 1964 and the current conditions assessment was based primarily on aerial photography 1998. In addition, aerial photographs from 1959 were used to assess conditions in the section of channel now inundated by Howard Hanson dam.

ENVIRONMENTAL SETTING

STUDY AREA DESCRIPTION

The Green River originates on the western crest of the Cascade Mountains (Figure 1). The Upper Green River flows almost thirty miles from the headwaters at Blowout Mountain, at an elevation of over 1,700 meters, to Howard Hanson Dam, which forms the downstream boundary of this subwatershed at Rivermile (RM) 64.5. The upper basin encompasses 598 square kilometers with approximately 7,735 km of mapped stream channels, including 267 km of fish-bearing streams (USFS 1996).

Average annual precipitation for the watershed is 215 centimeters (85 inches) per year. The mean annual snowfall at the Stampede Pass weather station is 1,112 centimeters (36.5 feet) per year (Western Regional Climate Center 1998). The highest peak flows occur in winter as a result of rain-on-snow events and the highest mean monthly streamflow occurs in May from snowmelt runoff.

GEOLOGY

Most of the Upper Green River subwatershed is dominated by andesite and basalt flows that were deposited 24 to 38 million years ago. This formation also includes volcanic sediments (pyroclastics) that are moderately to highly erosive. The basin also includes minor amounts of igneous intrusive, sedimentary, and metamorphic rocks. Upstream from Howard Hanson dam, the Green River valley was extensively modified by Pleistocene alpine glaciation approximately 20,000 years ago.

The valley floodplain consists primarily of alluvial deposits with lesser quantities of recessional outwash deposits in the vicinity of Howard Hanson dam and along the entire North Fork Green River.

HYDROLOGY

The elevation of the Upper Green River basin ranges from 370 to 1,725 m (1,210 to 5,660 feet), resulting in a range of precipitation zones from rain dominated to rain-on-snow dominated to snow dominated. Snow is the dominant form of precipitation for over fifty percent of the basin (USFS 1996).

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Notes:

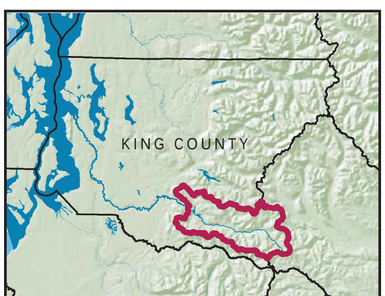
1. *The FODS watershed boundary was defined by R2 Consultants as part of the FODS (Factors of Decline Study) . The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.*
2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*
3. *Standard King County datasets used: drnbasin, wtrcrs, wtrbdy, April 2004.*

Figure 1

Study Area

Upper Mainstem Green River

- 60 River Mile and Number
- River/Stream
- FODS Watershed Boundary
- Open Water



Location Map

April 2004

File Name: 0405_UGR_StudyArea.ai LPRE

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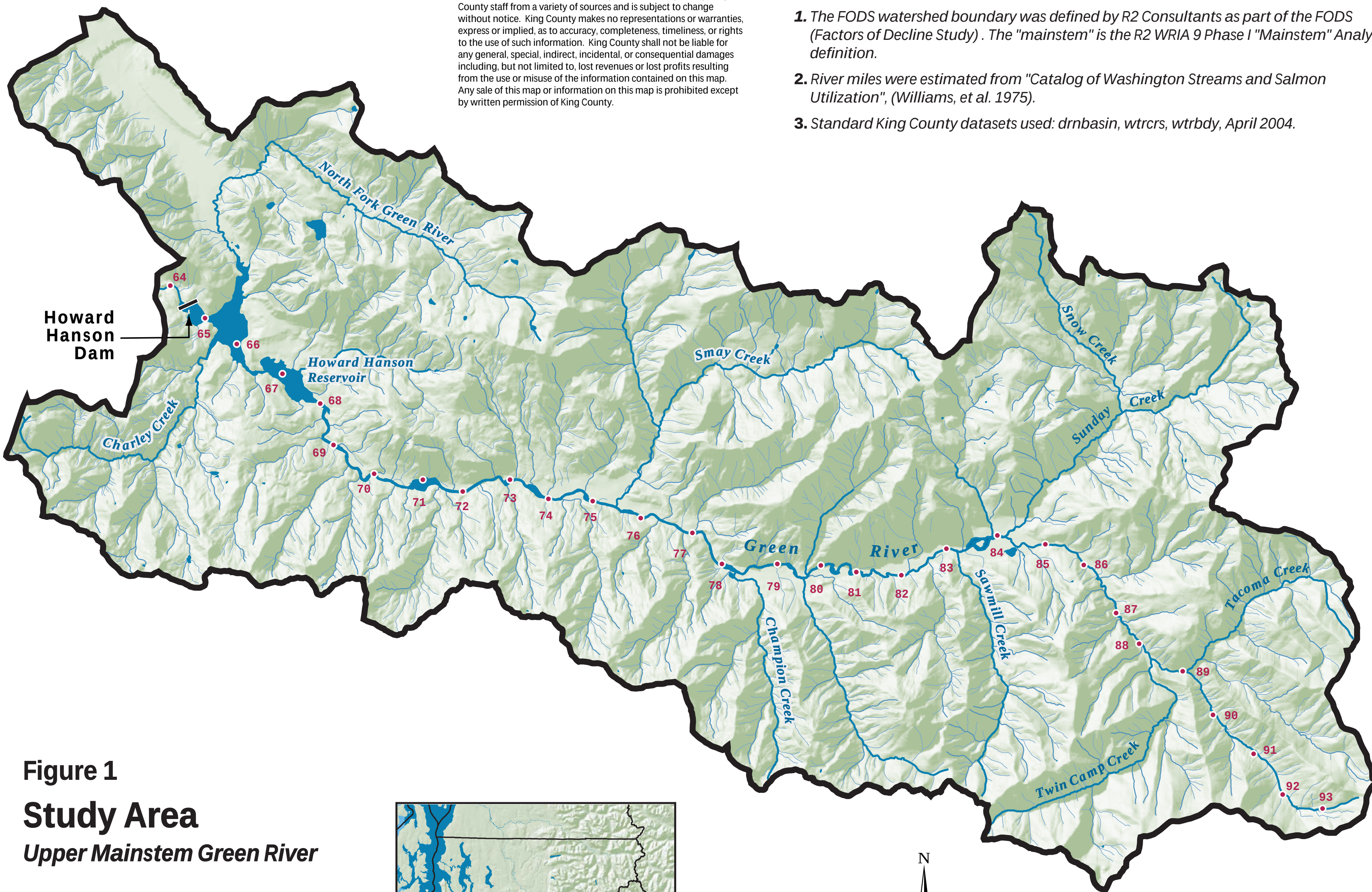
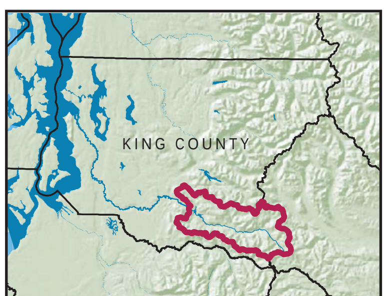


Figure 1

Study Area

Upper Mainstem Green River

- 60 River Mile and Number
- River/Stream
- FODS Watershed Boundary
- Open Water



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The highest peak flows occur in November through January as a result of rain-on-snow events. The highest peak flow on record for the Lester gaging station, estimated at 25,800 cfs, occurred in November 1990 (USGS 2004). Large floods (>15,000 cfs) also occurred in 1958, 1977, and 1984. The highest mean monthly flows generally occur in May from snowmelt.

SEDIMENT SUPPLY

Soil erosion and sediment delivery are expected to be low in an undisturbed forested watershed (Swanston 1991). Removal of vegetation by fire and subsequent soil erosion during large storm events would have provided large quantities of sediment in pulses to the tributaries and mainstem Green River. Landslides, as a result of earthquakes or saturation of slopes during heavy rains, would also provide periodic pulses of sediment. These processes are important in forming and maintaining the channel form and salmonid habitat.

METHODS

This study uses the methodology for mapping historical channel locations in a geographic information system (GIS) based upon methods established by Collins et al. (2003). The position of the mainstream Green River was mapped between Rivermile 64.5 and 85.0 from 1901/1910-11, 1964, and 1998 (Figure 2). Aerial photographs from 1959 were also used to map the position of river between Rivermile 64.5 to 70.0 in order to document stream channel conditions prior to inundation from Howard Hanson reservoir.

Fire history and seral stage maps were derived from U.S. Forest Service GIS products based upon field sampling of ecological units (USFS 1996).

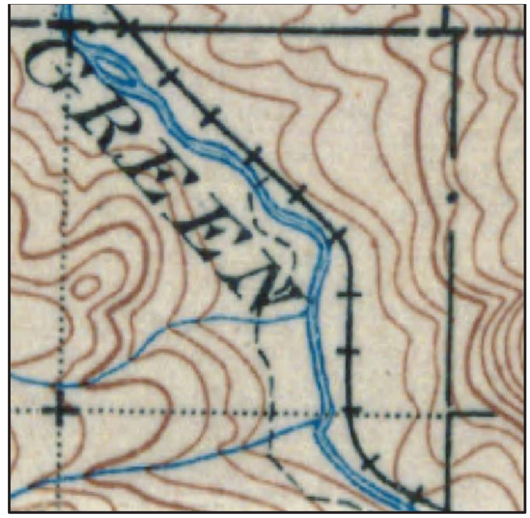
MAP SOURCES AND AERIAL PHOTOGRAPHS

The 1901 and 1910-11 U.S. Geological Survey (USGS) topographic maps for Snoqualmie Pass and Cedar Lake, at a scale of 1:125,000, were used to document the historical channel location (Marshall et al. 1913, Goode et al. 1956). The topographic maps were georeferenced and brought into GIS. Problems with historical topographical maps included difficulties with the cartographic techniques of that era and that the map scale was relatively low. This resulted in the mapped streams appearing relatively straight, with an extremely low sinuosity for a natural system. The stream channel differs in width considerably between the two topographic maps, which were mapped by different surveyors ten years apart. The General Land Office (GLO) maps (Brown 1891), dating from 1891, were consulted for the historical conditions but were not used for mapping channel location because topographic maps are considered more accurate.

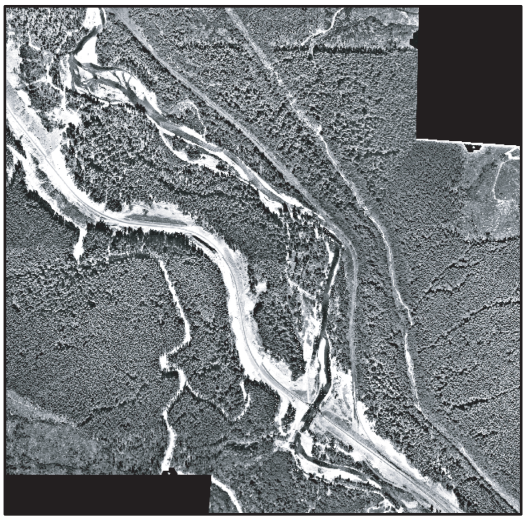
The 1959 black and white aerial photographs provided coverage only as far east as the town of Humphrey, which includes coverage of the area that was inundated by the dam in 1961 (King County, 1:12,000). The entire mainstem river within the study area was mapped using 1964 black and white aerial photographs (King County, 1:15,540). Both sets of aerial photographs were georeferenced and photomosaicked but were not orthorectified. This resulted in occasional matching problems along photo edges.

Aerial photography from Washington State Department of Natural Resources (1998, 1:14,000) was available in a digitized and orthorectified format and was used to document current channel conditions.

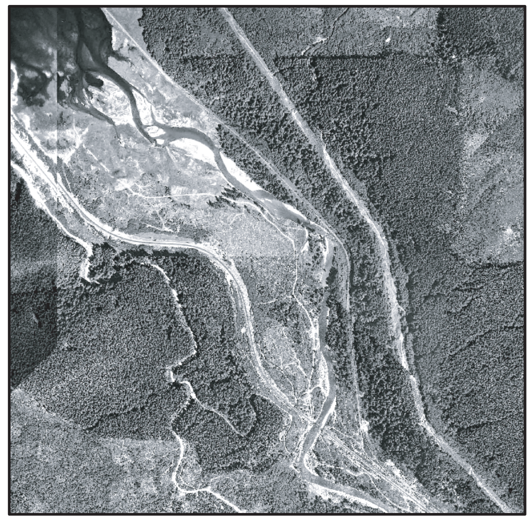
GLO Plant - 1897



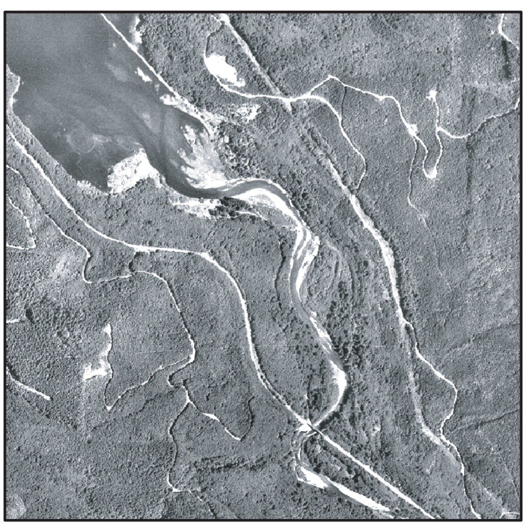
Cedar Lake 1:125,000 Quad - 1911



King County Aerial Photo - 1959



King County Aerial Photo - 1964



WA DNR Orthophoto - 1998

King County Orthophoto - 2002

0405 UGR photos.AI LPRE

Figure 2

Photo Comparison

Upper Mainstem Green River

0 0.5

Miles

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CHANNEL MAPPING

It was assumed that channel mapping during the USGS surveys (1901/1910-11) aerial photography was conducted during low-flow conditions. It was also assumed that streamflow conditions were relatively consistent for all three time frames in order to facilitate comparison of channel area and channel width. The mainstem stream channel mapped on the 1901 and 1910-11 USGS topographic maps appears to include the low-flow channel and point bars but does not appear to include areas of perennial vegetative patches.

The channel features were mapped in ESRI's Arcview GIS software at approximately 1:2,400 scale using map units defined by Collins and Sheikh (2003). The active channel was mapped as the low-flow channel and point bars. Vegetative patches were mapped as those areas that had perennial vegetation adjacent to the active channel. Forested islands, side channels, and wetlands were also mapped but not included in the active channel.

REACH DELINEATION OF SURVEY AREA

Assessment segments were identified for the entire Green River mainstem system as part the overall Strategic Assessment (WRIA 9 and King County WLR 2004). These segments were delineated based on geomorphic features. There are six segments in the upper Green River subwatershed, which range in length from 0.9 to 8.3 miles (Figure 3 and Table 1).

For the Upper Green River subwatershed, these segments were further stratified into smaller reaches that were consistent in stream gradient and channel confinement (Figure 3 and Table 1). Reaches were also delineated based upon the contribution by sediment and flow by major tributaries. These reaches ranged in length from 0.9 to 2.8 miles.

Table 1. Reach descriptions for the Upper Green River (RM 64.4-85).

Assessment Segment	River Reach	Reach Location (Rivermile)	Description
Segment 8	Reach 1	64.4 – 65.25	Howard Hanson dam to confluence with the N. Fork Green River
Segment 8	Reach 2	65.25 – 67.75	N. Fork Green to upper extent of reservoir
Segment 8	Reach 3	67.75 – 70.0	Upper extent of reservoir to Humphrey
Segment 8	Reach 4	70.0 – 72.7	Humphrey to confluence with Sylvester Creek
Segment 9	Reach 5	72.7 – 75.5	Sylvester Creek to confluence with Smay Creek
Segment 9	Reach 6	75.5 – 77.0	Smay Ck to confluence with Green Canyon Ck
Segment 10	Reach 7	77.0 – 77.9	Green Canyon Ck to beginning of confinement reach
Segment 11	Reach 8	77.9– 83.0	Upper extent of confined reach to Lester
Segment 11	Reach 9	83.0 – 84.1	Lester to confluence with Sunday Creek
Segment 12	Reach 10	84.1 – 85.0	Confluence with Sunday Creek to Railroad Trestle

(1) River miles were estimated from "Catalog of Washington Streams and Salmon Utilization," (Williams et al. 1975).

(2) Reaches 1 and 2 are seasonally inundated by Howard Hanson reservoir.

Notes:

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4. *River segment boundaries developed by King County Water and Land Resources Division.*

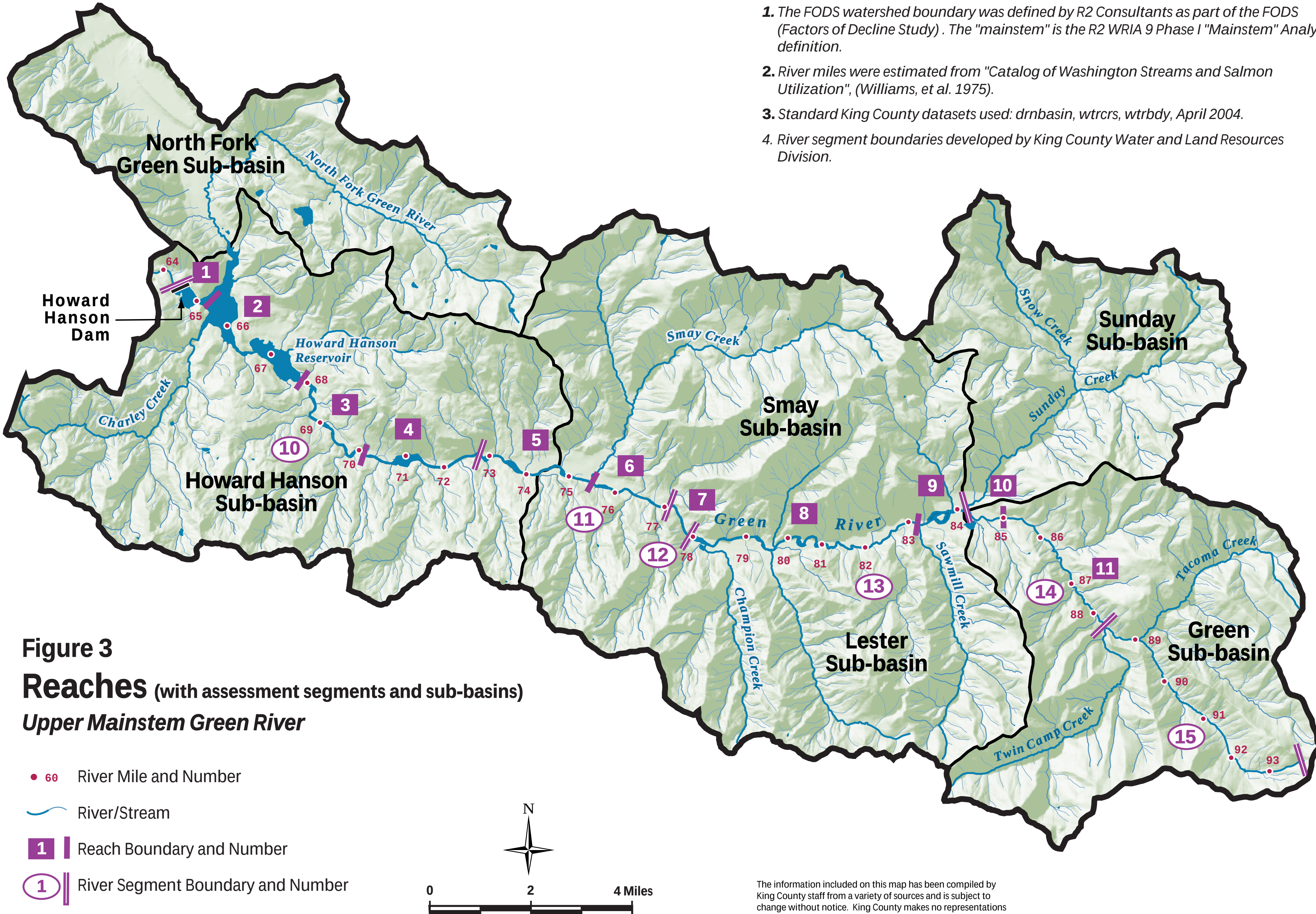

Figure 3

Reaches (with assessment segments and sub-basins)

Upper Mainstem Green River

- 60 River Mile and Number
- River/Stream
- 1 Reach Boundary and Number
- 1 River Segment Boundary and Number
- Sub-basin Boundary
- FODS Watershed Boundary
- Open Water

File Name: 0405_UGR_ReachSubs.ai LPRE

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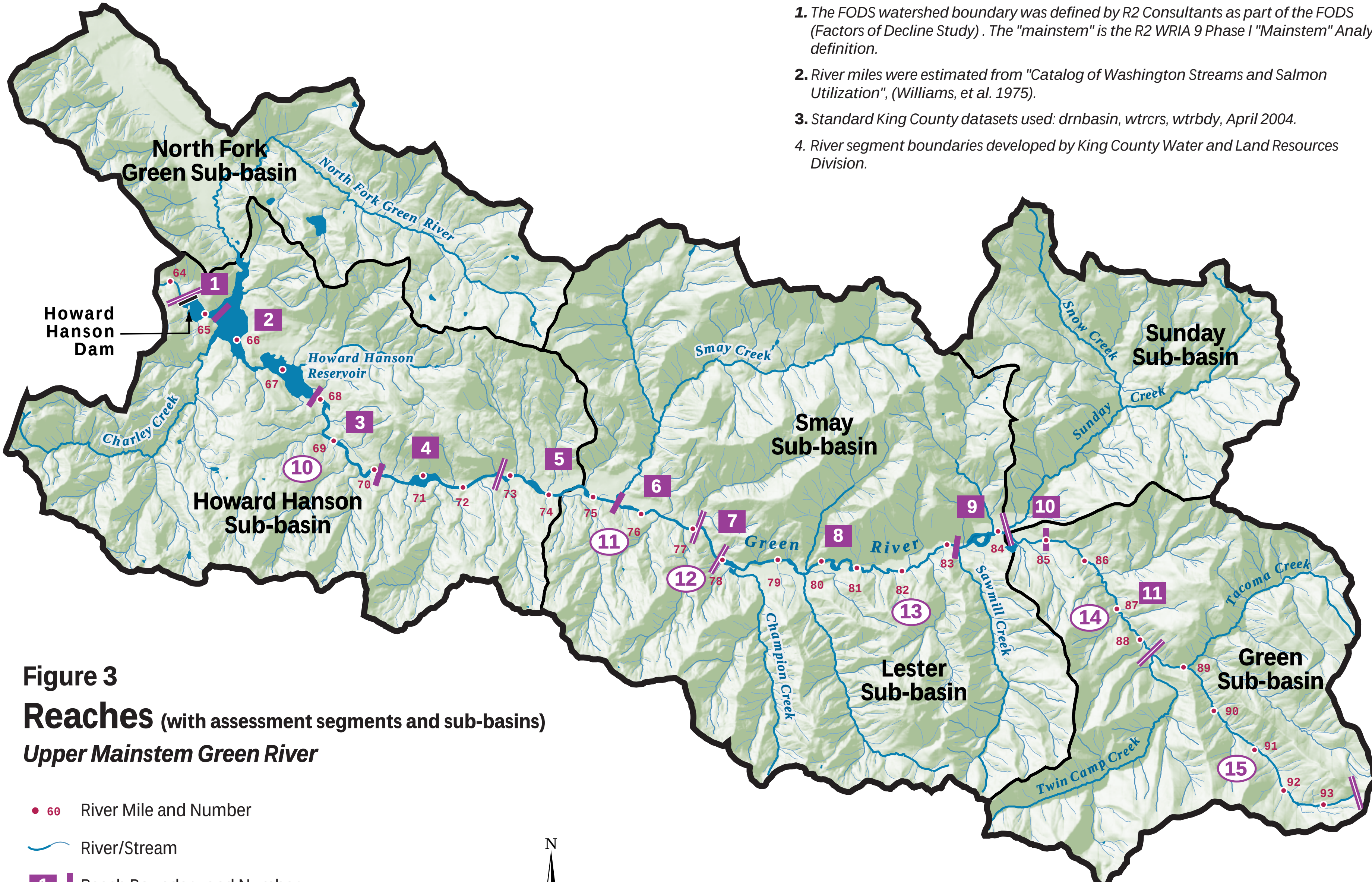

Figure 3

Reaches (with assessment segments and sub-basins)

Upper Mainstem Green River

- 60 River Mile and Number
- River/Stream
- 1 Reach Boundary and Number
- 1 River Segment Boundary and Number
- Sub-basin Boundary
- FODS Watershed Boundary
- Open Water

N

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STREAM CHANNEL CHARACTERISTICS METHODS

The channel floodplain confinement was defined as the ratio of the active channel width to the width of the valley bottom. This was modified from Bauer and Ralph (1999) in order to estimate the channel confinement using aerial photographs instead of bankfull and floodplain indicators that must be identified in the field. Confinement classes included:

Unconstrained: Valley bottom width > 4X active channel width

Moderately Constrained: Valley bottom width 2 - 4 times the active channel width

Constrained: Valley bottom width <2 times active channel width

Channel pattern was classified as straight, sinuous, or meandering based upon sinuosity (SI). The following categories were used based upon criteria defined by Mount (1995):

Straight .... SI < 1.05

Sinuous.................................. 1.05 < SI<1.5

Meandering .... SI > 1.5

WATERSHED CONDITIONS AND MANAGEMENT

This section on historical habitat conditions includes information on watershed and channel/valley bottom conditions. Watershed conditions include information on fire history, human activity including settlement, railroad construction, logging, road building, and dam construction activities. Channel and valley bottom conditions include channel characteristics, wetlands, land cover, riparian vegetation, and large woody debris. Table 2 chronicles the major policy and events that have affected the Upper Green River subwatershed, beginning with Native American settlements near Lester prior to 1900 and the construction of the Northern Pacific Railroad in 1886.

FIRE HISTORY

Erosion from fire can occur both episodically, in large pulses from landslides and debris flows, and chronically from surface erosion over time. Stream channels and aquatic species are dynamic and have adapted to these processes (Bisson et al., *in press*). Large-scale fires affected much of the upper basin in the early 1300s, 1500s, and 1700s (Figure 4) (USFS 1996). Extensive areas of burned timber are mentioned in the GLO survey notes of the upper basin. Brown (1891) notes in Township 20N Range 08E, "The remains of old forest killed by fire long ago. Undergrowth dense." Riparian areas typically would not have burned as frequently or as intensely as the rest of the watershed (USFS 1996), leaving more mature timber within the riparian area. Fires from sparks of passing trains resulted in smaller fires in the upper basin between 1888 and 1920 (Figure 5). Since 1920, fire prevention and suppression has resulted in a relatively small number (<700 hectares) of fires (USFS 1996).

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2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*

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4. *Fire data from U.S. Forest Service Watershed Analysis (1996).*

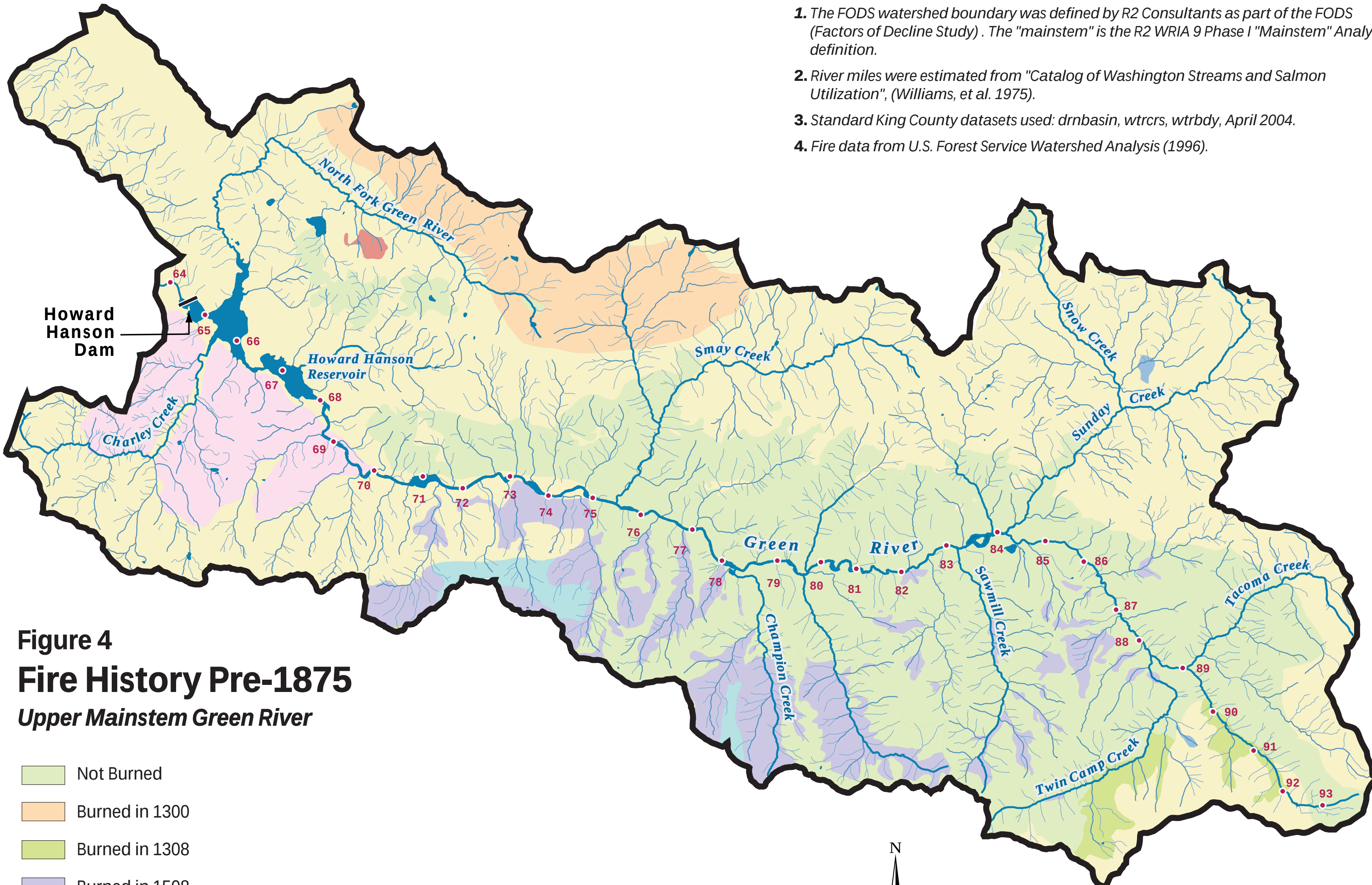

Figure 4

Fire History Pre-1875

Upper Mainstem Green River

- Not Burned
- Burned in 1300
- Burned in 1308
- Burned in 1508
- Burned in 1701
- Burned in 1800
- Burned in 1840
- Burned in 1873
- 60 River Mile and Number
- River/Stream
- FODS Watershed Boundary
- Open Water

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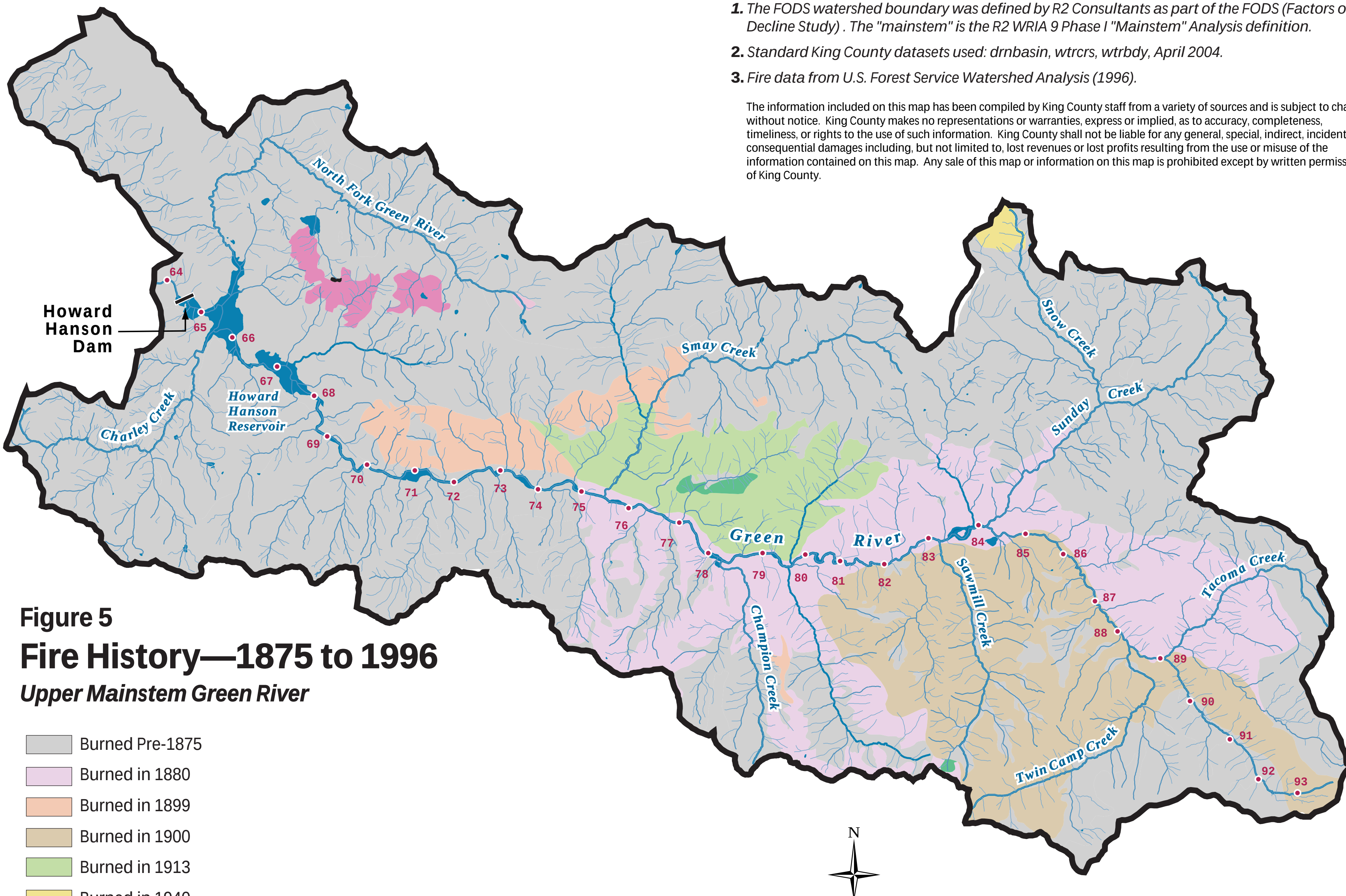

Figure 5

Fire History—1875 to 1996

Upper Mainstem Green River

- Burned Pre-1875
- Burned in 1880
- Burned in 1899
- Burned in 1900
- Burned in 1913
- Burned in 1940
- Burned in 1952
- Burned in 1956
- Burned in 1957
- Not Burned

- 60 River Mile and Number
- River/Stream
- FODS Watershed Boundary
- Open Water

April 2004

File Name: 0404_UGR_Fire1996.ai LPRE

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HUMAN ACTIVITY

Pre-European

Archeological research within the Green River drainage suggests that the current site of Lester was a Native American Indian Village (Hedlund et al. 1978). According to Boreson (1999), the area around the present site of Howard Hanson reservoir was used by the Skopamish people as a base camp for people going upriver to harvest and process fish within six miles of this area. Hedland also reports that Native American trails crossed the south side of the drainage, probably near Stampede Pass with a fork of this trail leading to a Meadow Pass-crossing of the Cascades. Native land management in the watershed included burning in the Huckleberry Mountain area to increase berry production (USFS 1996).

Railroad

The first major changes in the Upper Green River subwatershed from Euro-Americans began with the advent of transcontinental railroads (Table 2). Federal land grants were made to the railroad companies in 1864 in exchange for building the first transcontinental railroad. The route through Stampede Pass was identified in 1881 and construction by the Northern Pacific Railroad began in 1886 (Figure 6). Construction required large quantities of wood in the basin (Hollenbeck 1987) and also made the watershed accessible for timber harvest. Logging companies in the Upper Green River valley ran a total of approximately 55 miles of shorter spurs to the mainline between 1904 and 1955 (Hollenbeck 1987). Sparks from the brakes of passing trains ignited forest fires, thus increasing the frequency of fire in the subwatershed. Large quantities of fill material were used in the crossing of stream channels and likely contributed a large quantity of sediment to streams during railway construction (Faulkner 1997).

Figure 6. Construction of the railroad at a crossing of the Green River (1886). Photo courtesy of the Museum of History and Industry.

The railroad was taken out of active service in 1982 and brought back into service in 1996. In order to reactivate service, the rail bed was upgraded by placing several thousand linear feet of large rock along the Upper Green River at eight locations (Burlington Northern Railroad 1996), culverts were replaced, and improvements were made to the tunnel and snowshed.

The rail line parallels the Upper Green River along much of the study area (Figure 7), reducing the ability of the stream to meander, disconnecting the river from side channels, eliminating recruitment of large woody debris, reducing the amount of stream shade, and increased water velocities at bank hardening. At the turn of the century, as much as 57% of the mainstem river within Reach 7 was constrained by the rail line located either adjacent to the river or within the floodplain (Table 3). Currently, between 5% and 31% (Table 3) of the mainstem river is constrained by road and railroad revetments.

Table 2. Chronology of Policy and Events in the Upper Green River Basin

Date	Policy and Events	Source
Pre-1900	Seasonal Native American settlements located in Lester.	Hedlund et al.(1978)
1886-1897	Northern Pacific Railroad constructed through Stampede Pass. Railroad first put into service in 1888.	Burlington Northern Stampede Pass Environmental Checklist (1996)
1880-1913	Fires from trains or logging activity repeatedly burns portions of the Upper Watershed.	USFS Watershed Analysis (1996)
1897	Washington and Rainier forest reserves established to protect and minimize disturbance to watershed.	USFS Watershed Analysis (1996)
1900s	Settlement of Upper Watershed begins soon after completion of railroad. Peak population of Lester in 1920: 1,000	USFS Watershed Analysis (1996)
1901-1947	Shorter (1-22 miles each) segments of railway tracks constructed adjacent to Northern Pacific Railroad for logging in watershed.	Hollenbeck (1987)
1908	Snoqualmie National Forest created	USFS Watershed Analysis (1996)
1910	City of Tacoma authorized to construct gravity water supply system within the Green River watershed.	
1914	US Forest Service and City of Tacoma enter into a cooperative agreement	Tacoma Public Utilities (TPU) Green River Watershed Management Plan, Vol. II (1998)
1910-1930	Large-scale logging began in the Upper Basin.	TPU Habitat Conservation Plan (2001)
1912	Tacoma Water Diversion completed to divert water from Green River for municipal water supply.	Sato (1997)
1933	December 9 flood inundated 13,800 acres in lower portion of the Green River valley, resulting in an estimated $1,750,000 in damage.	Sato (1997)
1936	Army Engineer District begins looking for flood control project site within watershed.	

Date	Policy and Events	Source
1943	Bonneville Power Administration begins construction of transmission lines through the Upper Watershed.	
1946	December 11 flood recorded at 23, 200 cfs at Palmer and resulted in $1,350,000 in damages in lowland areas.	USACOE dam brochure (1979) and Sato (1997)
1958	November 22 flood results in second highest peak of record (22,000 cfs) at Lester gauging station.	USGS Water Supply(2004)
1959	Construction of Howard A. Hanson dam begins, including 13 miles of railroad relocation.	USACOE dam brochure (1979)
1960-1970	Private lands extensively logged.	TPU HCP (2001)
1961	Howard A. Hanson dam goes into operation on December 25.	TPU Green River Watershed Management Plan, Vol. II (1998)
1965	Condemnation of 1,450 acres of private land within the Green River watershed to protect water quality.	TPU Green River Watershed Management Plan, Vol. II (1998)
1967	City of Tacoma purchases the town-site of Lester	Colvin (1984)
1977	December flood results in 4th highest peak of record at the Lester gaging station, resulting in extensive damage to the logging road system.	USGS Water Supply (2004)
1982	Burlington Northern takes railway route through Green River Watershed out of service.	Burlington Northern Railroad Stampede Pass SEPA Environmental Checklist (1996)
1983	Burlington Northern Sante Fe Railroad line taken out of service.	Burlington Northern Railroad Stampede Pass SEPA Environmental Checklist (1996)
1984	January 24 flood results in third highest peak of record at Lester gauging station (16,600 cfs). Extensive damage to road system; high turbidity causes City of Tacoma to switch to well system for water supply	USGS Water Supply (2004)
1990	November flood event result in highest peak discharge of record (est. 28, 500 cfs at Lester gauging station).	USGS Water Supply (2004)
1996	Burlington Northern rail line put back into service through the Green River watershed due to increasing demand for rail transportation.	Burlington Northern Railroad Stampede Pass SEPA Environmental Checklist (1996)
2002	Gertrude Murphy, last resident of Lester, dies at 99 years of age.	*The Seattle Times* (October 2, 2002)

Notes:

1. *The FODS watershed boundary was defined by R2 Consultants as part of the FODS (Factors of Decline Study) . The "mainstem" is the R2 WRIA 9 Phase I "Mainstem" Analysis definition.*
2. *Standard King County datasets used: drnbasin, wtrcrs, wtrbdy, April 2004.*
3. *Railroad and road data obtained from King County Department of Transportation.*

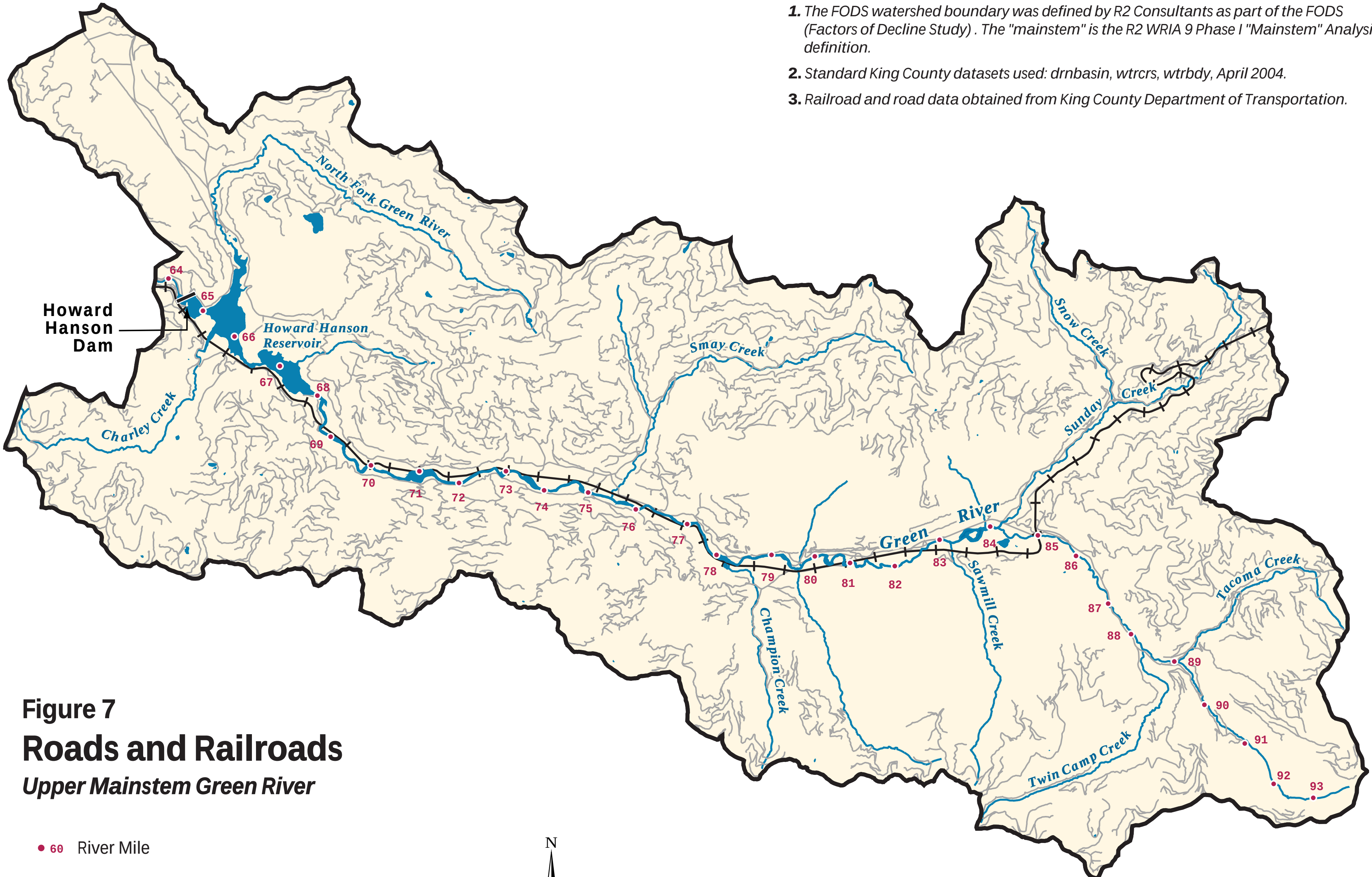

Figure 7

Roads and Railroads

Upper Mainstem Green River

- 60 River Mile
- Road
- Railroad
- River/Stream
- FODS Watershed Boundary
- Open Water

N

0 2 4 Miles

April 2004

File Name: 0404_UGR_RR-Rds.ai LPRE

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Notes:

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2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*

3. *Standard King County datasets used: wtrcrs, wtrbdy, April 2004.*

4. *The road and railroad segments were derived from aerial photo analysis by King County Water and Land Resources Division staff, January 2004.*

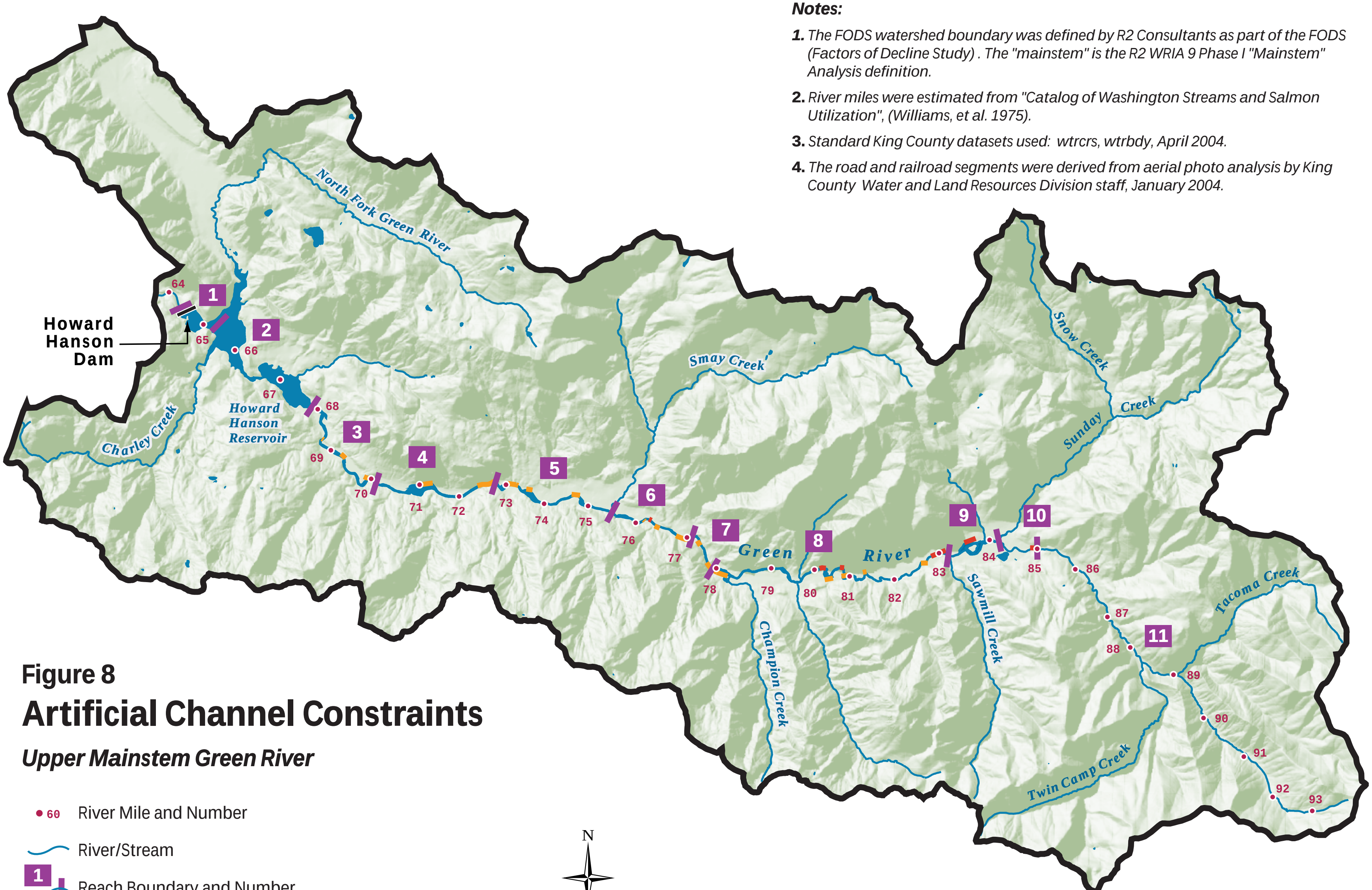

Figure 8

Artificial Channel Constraints

Upper Mainstem Green River

- 60 River Mile and Number
- River/Stream
- 1 Reach Boundary and Number
- Stream Adjacent Parallel Road Segments
- Stream Adjacent Parallel Railroad Segments
- FODS Watershed Boundary
- Open Water

N

0 2 4 Miles

April 2004

File Name: 0404_UGR_ChCons.ai LPRE

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Table 3. Influence of railroad/road on the Upper Green River (RM 64.5-85) by percentage of channel length.

Reach Number	Rivermile	1901	1964	1998
Reach 1 (1)	64.4 - 65.25	29%	N/A	N/A
Reach 2 (1)	65.25 - 67.75	30%	N/A	N/A
Reach 3	67.75 – 70.0	10%	0%	5%
Reach 4	70.0 – 72.7	25%	20%	26%
Reach 5	72.7 – 75.5	4%	30%	20%
Reach 6	75.5 – 77.0	2%	33%	19%
Reach 7	77.0 – 77.9	57%	17%	31%
Reach 8	77.9 – 83.0	16%	5%	19%
Reach 9	83.0 – 84.1	0%	14%	15%
Reach 10	84.1 – 85.0	2%	2%	13%

(1) Reaches 1 and 2 seasonally inundated due to Howard Hanson Dam.

Timber Harvest

Logging activity began in the 1880s to provide materials for construction of the Northern Pacific railroad (Hollenbeck 1987). Timber harvest during the late 1800s was concentrated in the Maywood, Morgan, Champion, Friday, and Rock Creek subbasins and along the mainstem Green River. The amount of area harvested during this time period rarely exceeded 15% of the subwatershed area (USFS 1996).

Shorter rail lines vastly opened up areas for logging of the lower portion of the basin and shorter (1-22 miles each) segments of railway tracks were constructed for additional access beginning in 1910 and continuing until about 1940 (USFS 1996). The amount of logging during this time exceeded 40% of the subwatershed area during peak harvest periods in the Sylvester, North Fork Green, Gale, Green Canyon, Lester, Sawmill, and McCain Creek subbasins.

Logging accelerated again between 1960 and 1977 (USFS 1996) through all subwatersheds. More than 60% of the area within the Humphrey, Charley, Elder, Canton, Smay, Intake, and West Creek subbasins were harvested during this time period. Currently, most of the Upper Green River watershed exceeds the level of concern (12% vegetative disturbance) established by the Mt. Baker-Snoqualmie National Forest for causing unacceptable cumulative watershed effects (USFS 1996).

Road construction

Logging roads can adversely impact aquatic and terrestrial ecosystems by increasing the risk of landslides (e.g., mass wasting events), restricting lateral river migration, concentrating runoff, limiting fish passage, and substantially increasing surface erosion rates of forest soils. Logging roads can also increase peak flows and reduce base flows of streams by reducing the infiltration of rainfall and snowmelt through soils, and by intercepting subsurface flows. The increased sediment loads and changes in streamflow caused by logging roads often lead to major alterations in stream channel morphology including channel widening, loss of pool volumes due to sedimentation, and bank and channel instability (Harr 1977, Reid 1981, Furniss et al. 1991).

Sediment production to streams from roads can vary depending upon the road condition and construction type, road dimensions, surfacing, traffic, and proximity to streams. A history of poor road construction techniques resulted in massive failures in the 1977 storm event with sediment deposited directly in stream channels (Figure 9).

Figure 9. Culvert failure on Forest Service Road 5403 following 1977 flood events

The current road density was calculated by major subbasin based upon the King County Department of Transportation network (1998). The Upper Green River subwatershed was divided into six major subbasins in order to calculate road density (Figure 4). Road density ranged from 1.8 km/km^2 in the South Middle subbasin to 3.5 km/km^2 in the Sunday Creek subbasin (Table 4). Roads constructed by Bonneville Powerline Administration (BPA) were not included in the road density figures. The BPA roads are unsurfaced and, combined with inadequate drainage in some locations, produce locally high quantities of sediment during runoff events (USFS 1996).

Forest roads have substantially increased the amount of sediment contributed to streams in the Upper Green River subwatershed. Watershed analyses conducted by subbasin examined both surface erosion from roads and natural and management-related mass wasting events. As part of this analysis process, a surface erosion study in the Upper Green River and Sunday Creek subbasins (Figure 3) found that forest roads were contributing a substantial amount of sediment to stream channels (Evans 2002). Roads were determined to be a major factor in mass wasting events, commonly as a result of culvert and sidecast fill failures (Krogstad and Reynolds 2002).

Within the Howard Hanson and Smay Creek subbasins, approximately 50% of the landslides were related to land management activities, particularly roads (Faulkner 1997). Road sediment from surface erosion was estimated to exceed background levels with the lower Green River, Canton Creek, and Gale Creek subbasins.

Mass wasting analysis within the North Fork Green subbasin identified 79 landslides, with approximately 80% of these associated with roads (Laird 1997). A high portion of these landslides were found to deliver sediment directly to streams. Tributary basins within the Lester subbasin have been affected by fine sediment from mass wasting scarps and road erosion (Toth 1997)

Table 4. Current road density by subbasin in the Upper Green River subwatershed (source: King County Department of Transportation road data, 1998).

Watershed Analysis Area	Road density (km/km^2)
Green	2.5
North Fork Green	2.9
Smay Creek	2.9
Howard Hanson	3.0
Lester	1.8
Sunday Creek	3.5

Dam

In 1936, the public and Congress requested that the US Army Engineer District, Seattle begin searching for a dam site for flood control on the Green River. Preliminary work began in 1955, with over 21 kilometers of rail line relocated from the dam and reservoir area in 1956 (Galster 1989). Construction began in 1959 and the dam began operation in December 1961. The supplementation of instream flows by releasing water in the summer was anticipated to result in annual economic benefits of $59,000 to fisheries (US Army Corps of Engineers 1946). Construction of the dam resulted in the conversion of 12.2 km of mainstem stream to laucustrine habitat.

Power lines

Bonneville Power Administration began powerline construction in the 1940s to carry power produced by dams in the Columbia basin to Western Washington. Four powerline corridors traverse Sunday Creek and follow the Green River westward. Brush and woody vegetation are removed on a regular basis from under the powerlines in order to reduce risk of fire or damage to the powerlines. The powerline corridors closely follow Sunday Creek in several locations and also cross many smaller tributaries. A lack of vegetation in the power line corridor along stream channels results in lack of shade and large woody debris recruitment, exacerbating bank instability and creating an environment conducive to weed species.

The powerline and associated vegetation removal appears to have a strong influence on stream temperatures (USFS 2003).

HISTORICAL WATERSHED AND CHANNEL CONDITIONS

Channel conditions

The 1901 USGS topographic maps delineate the Upper Green River as a relatively straight channel along its entire length. This is likely due to limitations in cartographic techniques at the time for mapping channels in mountainous terrain and the fact that the scale of the map is low (1:125,000). Stream channel width is higher in the uppermost reaches (Reaches 9 and 10), and probably reflects the fact that different surveyors surveyed these two reaches than the remainder of the river. One forested island, approximately one hectare in area, was delineated in Reach 2 on the 1901 topographic maps (Table 5).

Table 5. Historical channel characteristics for the Upper Green River (1901 and 1910-11)

	Channel feature		
Reach Number	**Active Channel Area (hectares)**	**Forested Islands Area (hectares)**	**Avg. Channel Width (meters)**
Reach 1	6.2	0	39
Reach 2	23.1	1.1	36
Reach 3	15.8	0	40
Reach 4	15.7	0	48
Reach 5	14.9	0	43
Reach 6	11.0	0	39
Reach 7	4.4	0	38
Reach 8	41.0	0	52
Reach 9	12.1	0	71 (1)
Reach 10	10.1	0	74 (1)

(1) Stream channel width is higher in Reaches 9 and 10 and likely reflects the fact that different surveyors surveyed these uppermost reaches.

Wetlands

Brown (1891) describes wetlands near the confluence of the Green River and North Fork Green River as a "spruce and cedar swamp 27.50 chains" (approximately 550 meters wide). This location corresponds to two inter-connected swamps identified and mapped by the US Army Corps of Engineers (Figure 10), with a total size of approximately 32 hectares (Sylvester and Carlson 1961). These wetlands were connected to the North Fork Green River by an outlet channel and likely provided rearing area and refugia from high flows for salmonids.

Map Source:
Sylvester, R.O., and D.A. Carlson. 1961. *A study of water quality in relation to the future Howard A. Hanson Dam Impoundment on the Green River, Washington.* Prepared for Corps of Engineers, U.S. Army, Seattle District. University of Washington, Seattle, WA.

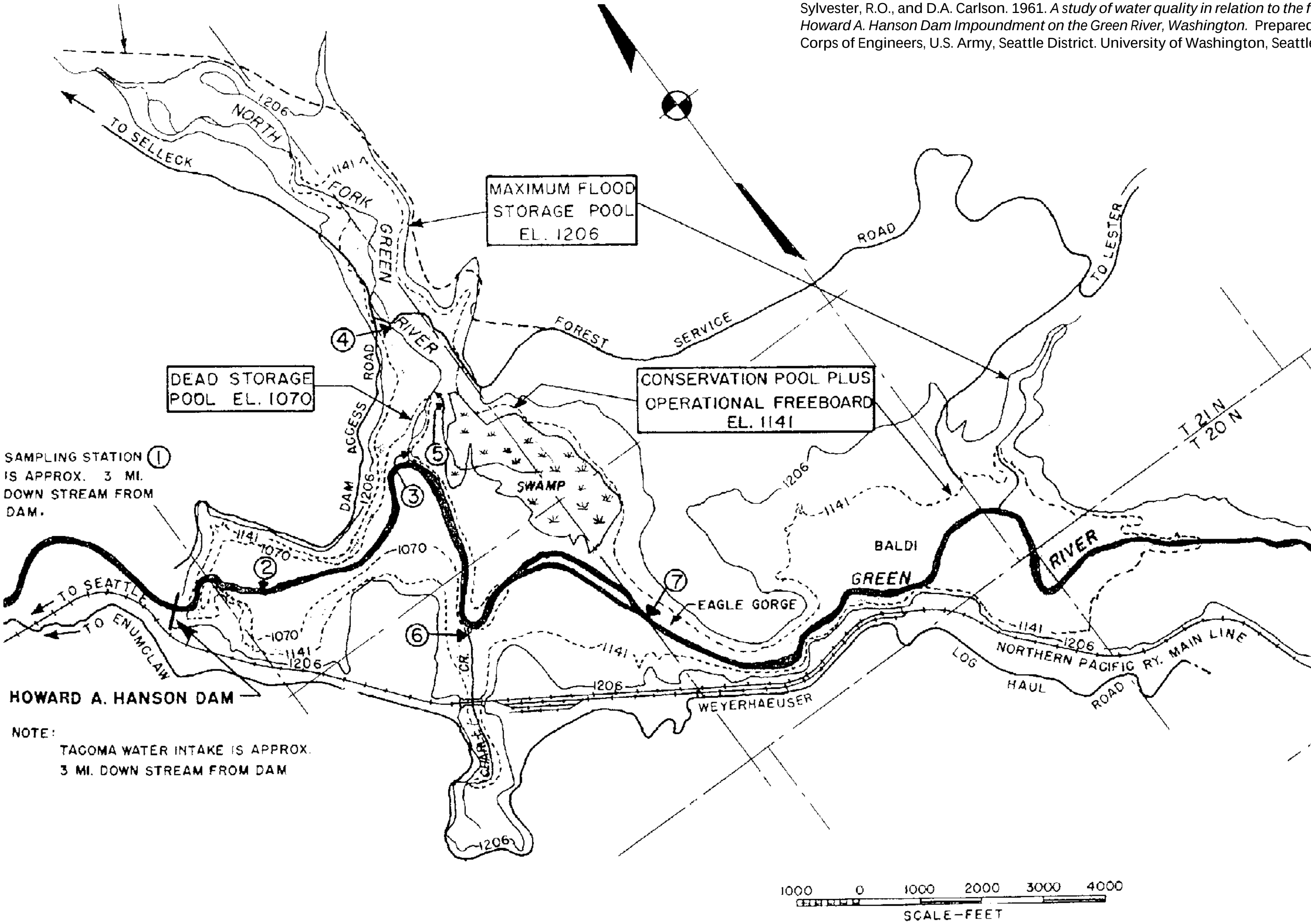

Figure 10

Howard Hanson Reservoir Area–1961

Upper Mainstem Green River

File Name: 0405_UGR_Dam.ai LPRE

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Water and Land Resources Division

Vegetative Cover

Brown (1891) repeatedly notes in the GLO surveys the heavy timber and brush throughout the watershed.

> "Heavily timbered with hemlock, fir, cedar and pine. Dense undergrowth …with salal and huckleberry and vine maple. Mountains heavily timbered with dense undergrowth." (Brown 1891).

This description of dense vegetative cover is consistent with the mid- to late seral species (Figure 10) predicted for pre-management conditions circa 1875 from the US Forest Service Watershed Analysis (1996). It was estimated for this time period prior to 1875, less than 1% of the Upper Green subwatershed was in the early seral stage, 75% of the area was in mid seral stage, and 26% of the area was in late seral stage.

Riparian vegetation

Riparian vegetation was frequently characterized as a "Dense growth of alder, cottonwood, and maple on (valley) bottom" (Brown 1891). Brown also noted that, "The soil along the Green River and its tributaries and through the valley…is first class." Riparian vegetation commonly mentioned in the GLO notes includes alder (*Alnus rubra*), cedar (*Thuja plicata*), hemlock (*Tsuga heterophylla*), and maple (*Acer macrophyllum*). The minimum diameter size tree used as a bearing tree was 7.5 cm (Collins et al. 2003), however, the smallest size tree noted for the Upper Green was 30 cm. The largest size diameter trees ranged from 90 – 182 cm and were predominantly cedar trees. Yew (*Taxus brevifolia*) and spruce (*Picea sitchensis*) trees were also infrequently mentioned.

Large woody debris

Instream woody debris was not mentioned in the GLO notes (Brown 1891). In order to estimate the quantity of instream wood prior to European settlement, studies of instream wood quantity and volumes in unmanaged stream basins in Alaska and Western Washington were used for comparison. For streams similar in size to the Green River, these studies found a range of 240 to 2,080 pieces of large woody debris per kilometer (Table 6). These studies were consistent in using a minimum size criteria for LWD of 10 cm diameter and 1 meter long, except for Robison and Beschta (1990), in which the minimum LWD size criteria was 20 cm diameter and 2 meters long.

Table 6. Quantity of LWD pieces per meter for channels >20m in studies of unmanaged forests in Alaska and Washington.

Author(s)	LWD frequency (pieces/km)	Location
Cedarholm et al. (1989)	240	Washington
Murphy and Koski (1989)	458	Southeast Alaska
Robison and Beschta (1990)	420	Southeast Alaska
Fox (2001)	570-2080	Western Washington

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Notes:

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2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*
3. *Standard King County datasets used: drnbasin, wtrcrs, wtrbdy, April 2004.*
4. *Seral stage data from U.S. Forest Service Watershed Analysis (1996).*

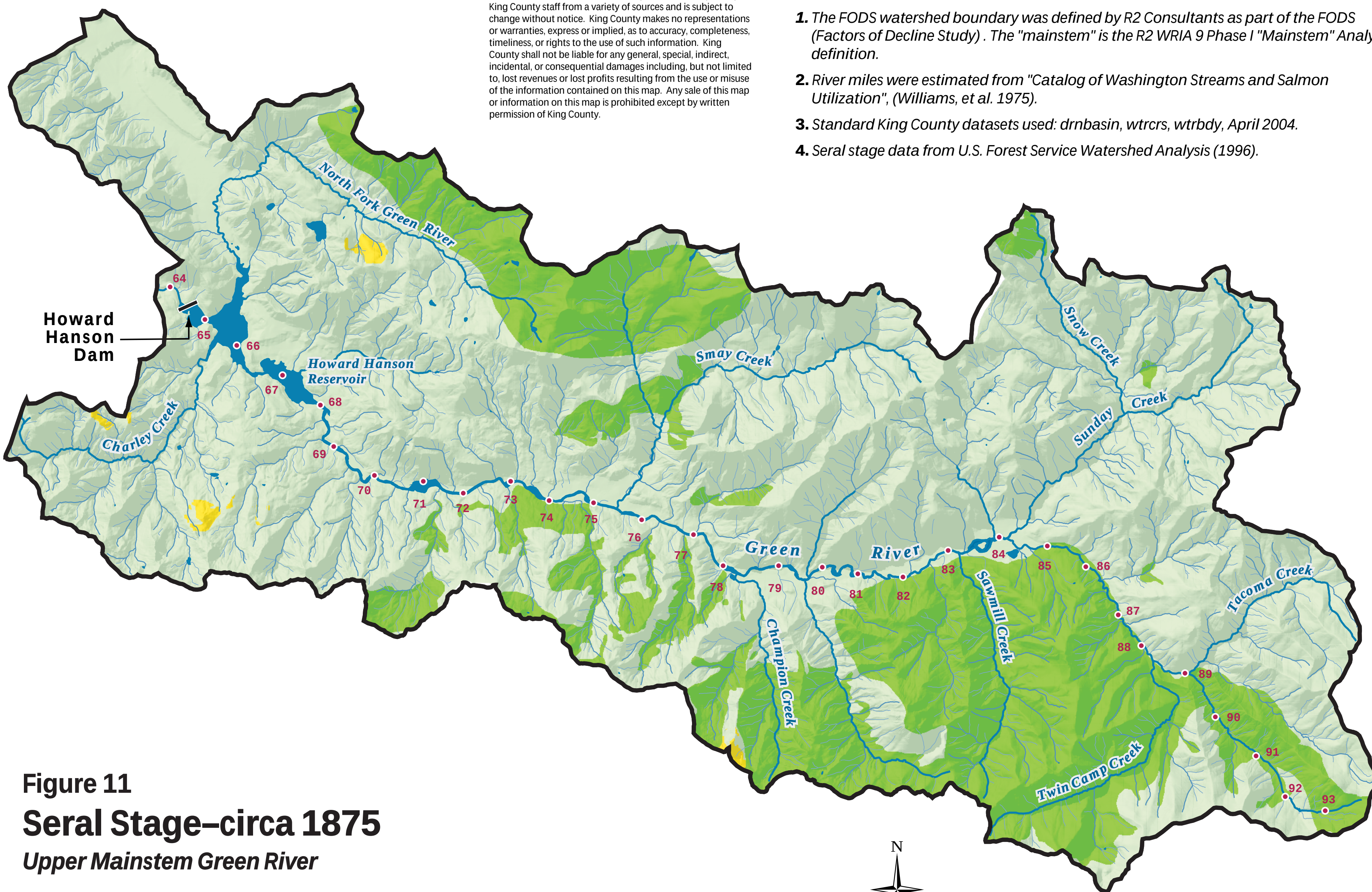

Figure 11
Seral Stage–circa 1875
Upper Mainstem Green River

- Non-forested
- Early Seral Stage
- Middle Seral Stage
- Late Seral Stage
- 60 River Mile and Number
- River/Stream
- FODS Watershed Boundary
- Open Water

April 2004

File Name: 0404_UGR_Seral1875.ai LPRE

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CURRENT WATERSHED AND CHANNEL CONDITIONS

Channel characteristics

Channel characteristics by reach were calculated from the 1998 mapped channel location (Table 7). The resolution of the aerial photographs limited the amount of side channels and wetlands that could be accurately mapped.

Reach 1, located between Howard Hanson dam and the confluence of the North Fork Green River (RM 64.4 to 65.25), is seasonally inundated by the reservoir between spring and fall. Reach 2 (RM 65.25 to 67.75) extends from the confluence of the North Fork Green River to the upper extent of the reservoir. This reach is also seasonally inundated by the reservoir and becomes laucustrine habitat during summer and fall

Reach 3, from the upper extent of the reservoir to the townsite of Humphrey (RM 67.75 to 70), is a sinuous channel located in an unconfined reach with a gradient of 0.6%. Analysis of the 1959 aerial photographs indicates that the river was artificially straightened between 1959 and 1964, during construction of the Howard Hanson dam. The upper reach break for Reach 4 (RM 70 to 72.7) coincides with landslide deposits on the south side of the channel. The reach extends from the original townsite of Humphrey to the confluence with Sylvester Creek. The channel pattern is straight and the gradient is 0.4% gradient.

Reach 5 begins at the confluence with Sylvester Creek (RM 72.7) and ends at the confluence with Smay Creek (RM 75.5). The gradient of this reach is 0.6% and the channel is unconfined. The Smay Creek watershed has been extensively harvested and likely contributed to the substantial amount of sediment input to the Green River.

Reach 6 extends from Smay Creek (RM 75.5) to Green Canyon Creek (RM 77.0). This has a gradient of 0.9%, and the channel pattern is sinuous.

Reach 7 (RM 77-77.9) is the only confined reach within the study area and has a higher channel gradient (1.0%) compared to the other mainstem segments included in this study. The upper reach break coincides with a change in geology from alpine glacial deposits to andesite and basalt flows. Reach 8 (RM 77.9 to 83) is located within glacial alpine deposits. The channel is unconfined within the valley bottom and has a sinuous channel pattern. The gradient is 0.7%.

Reach 9, from the townsite of Lester (RM 83) to the confluence with Sunday Creek (RM 84.1), is located within a broad alluvial floodplain. The gradient is 1% and the channel pattern is sinuous. The upper extent of Reach 10 (RM 84.1 to 85), is located at the railroad trestle and coincides with mapped landslide deposits on the south side of the Green River. The gradient is 0.9% with a straight channel pattern.

Table 7. Reach characterization for current conditions of the Upper Green River (RM 64.5-85).

River Reach (1)	Reach location	Avg. channel width in 1998 (meters)	Average gradient (%)	Sinuosity	Channel pattern	Floodplain confinement
Reach 1 (2)	64.5 – 65.25	N/A	N/A	N/A	N/A	N/A
Reach 2 (2)	65.25 – 67.75	N/A	N/A	N/A	N/A	N/A
Reach 3	67.75 – 70.0	67	0.6	1.09	sinuous	Unconfined
Reach 4	70.0 – 72.7	45	0.4	1.03	straight	Unconfined
Reach 5	72.7 – 75.5	75	0.6	1.15	sinuous	Unconfined
Reach 6	75.5 – 77.0	29	0.9	1.08	sinuous	Unconfined
Reach 7	77.0 – 77.9	21	1.0	1.03	straight	Confined
Reach 8	77.9 – 83.0	40	0.7	1.22	sinuous	Unconfined
Reach 9	83.0 – 84.1	103	1.0	1.23	sinuous	Unconfined
Reach 10	84.1-85.0	140	0.9	1.06	straight	Unconfined

(1) River miles estimated from Williams (1975)

(2) Reaches 1 and 2 are seasonally inundated by Howard Hanson reservoir.

Wetlands

The National Wetland Inventory and Forest Service vegetation database indicates many wetlands throughout the entire upper basin. In addition, Fuerstenberg et al. (1996) found numerous wetlands present in the floodplain of the Upper Green River above the dam. These wetlands were likely present historically but not recorded on the early topographic maps or noted in the GLO surveys. Many of the existing wetlands have been impacted by road construction, either through filling in of wetland areas or changes to the hydrology (USFS 1996).

Vegetative cover

Forestry continues to be the primary land use in the upper watershed. Other factors affecting the vegetative cover include Howard Hanson dam and reservoir, Burlington Northern Railroad, and Bonneville Power Administration transmission corridors. Current forest conditions in the Upper Green River subwatershed are primarily in early seral (40%) and mid-seral (50%) stages, with 10% of the subwatershed in late-seral stage (Figure 12). Much of the existing late seral forest stands are located in riparian areas within headwater streams or areas of very steep slopes.

Riparian vegetation condition

Much of the riparian corridor was harvested during the original timber harvest and or burned in fires at the turn of the century (Faulkner 1997). Currently, riparian vegetation along the mainstem Green River is predominantly small to medium-sized deciduous or mixed deciduous and coniferous stands (Figure 13) with less than 1% of the riparian zone in pure coniferous stands (Kerwin and Nelson 2000). The area immediately surrounding Howard Hanson reservoir is bare ground due to seasonal inundation.

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4. *Standard King County datasets used: drnbasin, wtrcrs, wtrbdy, April 2004.*
5. *Seral stage data from U.S. Forest Service Watershed Analysis (1996).*

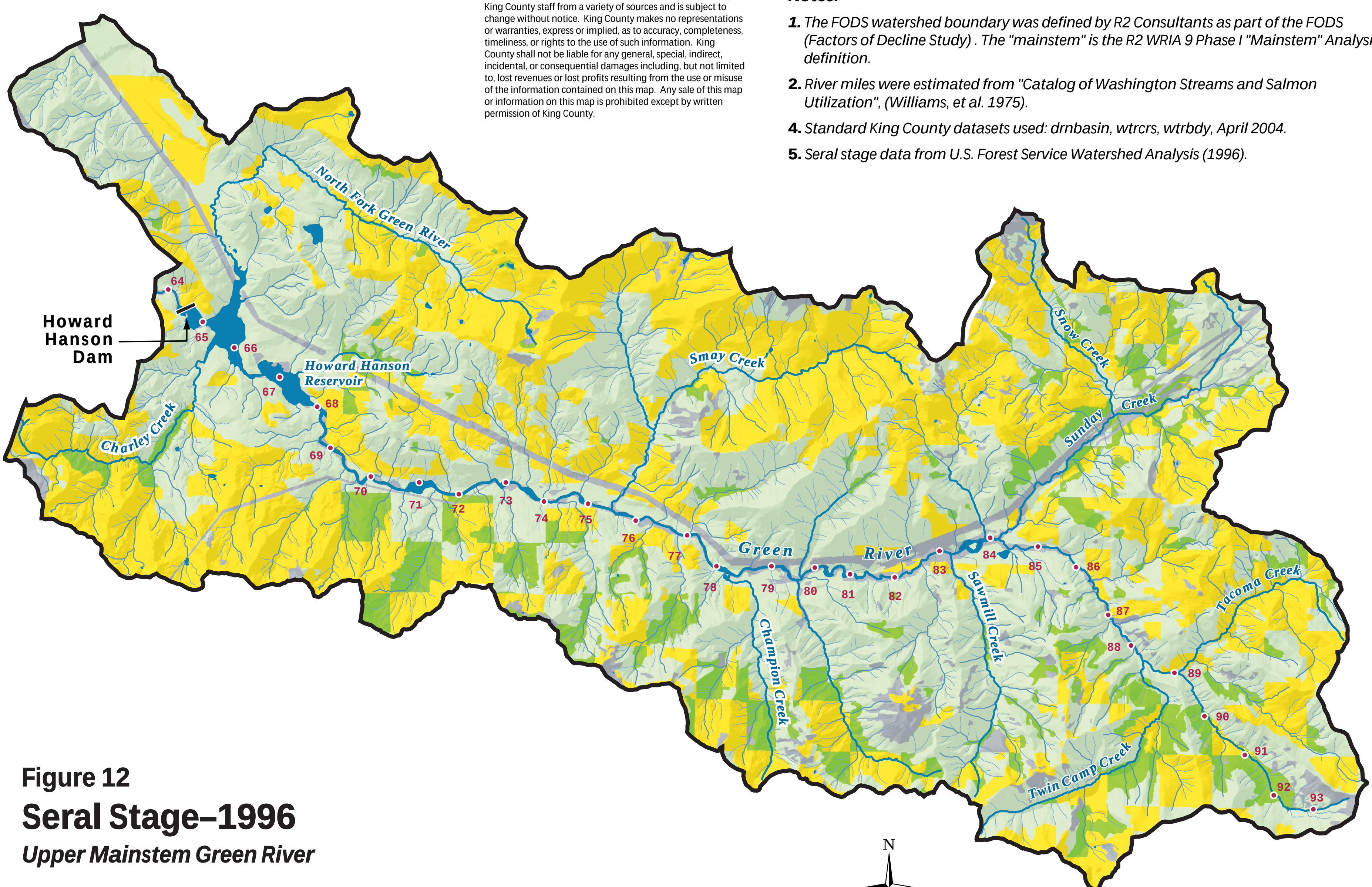

Figure 12

Seral Stage–1996

Upper Mainstem Green River

	Non-forested	60	River Mile and Number
	Early Seral Stage		River/Stream
	Middle Seral Stage		FODS Watershed Boundary
	Late Seral Stage		Open Water

N

0 2 4 Miles

April 2004

File Name: 0404_UGR_Seral1996.ai LPRE

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2. *River miles were estimated from "Catalog of Washington Streams and Salmon Utilization", (Williams, et al. 1975).*
3. *Standard King County datasets used: drnbasin, wtrcrs, wtrbdy, April 2004.*
4. *Data on riparian conditions in the upper Green River subwatershed was derived from U.S. Forest Service and Plum Creek (1996-1997) and compiled for the* Habitat Limiting Factors and Reconnaissance Assessment Report–Green/Duwamish and Central Puget Sound Watersheds *published by King Co. in 2000. The width of the vegetation shown has been exaggerated for better readability. Actual width varies between 50-300 ft from the mainstem.*

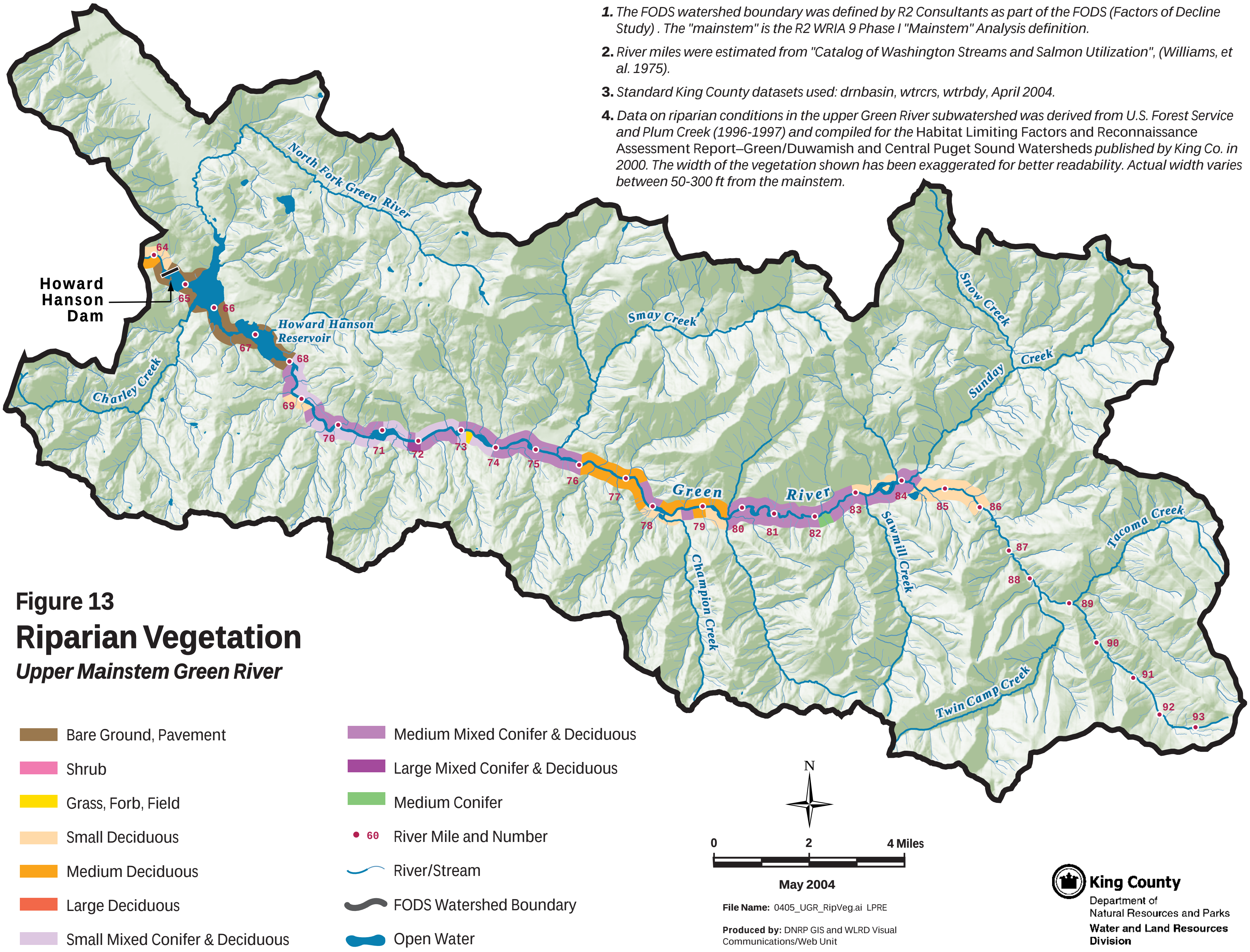

Figure 13

Riparian Vegetation

Upper Mainstem Green River

May 2004

File Name: 0405_UGR_RipVeg.ai LPRE

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Large woody debris

Recent surveys conducted for the US Army Corps of Engineers within Reaches 4 and 5, found an average of 4.5 pieces of large wood (>30.5 cm diameter and 9.1 meters long) per kilometer with much of the woody debris (89%) not functioning within the bankfull channel (HDR Engineering 2002). As part of the Lester Watershed Analysis, two segments of the mainstem Green River were inventoried. These inventories within Reaches 7 and 8 found 21 and 68 pieces LWD/km respectively using a minimum size criteria of 10 cm diameter and 1 m long (Toth 1997). No other data on LWD were found for other reaches in the Upper Green River subwatershed.

Potential chinook salmon spawning

Core areas for potential chinook spawning were identified in the section of Green River within Reaches 5, 9, and 10 and portions of Reach 7 (Figure 14) (Martin et al. 2004). These core areas were based upon network geometry as influenced by effects of tributaries at tributary confluences, variation in valley width, landslides, bedrock outcrops, and channel meanders (Martin and Benda 2003).

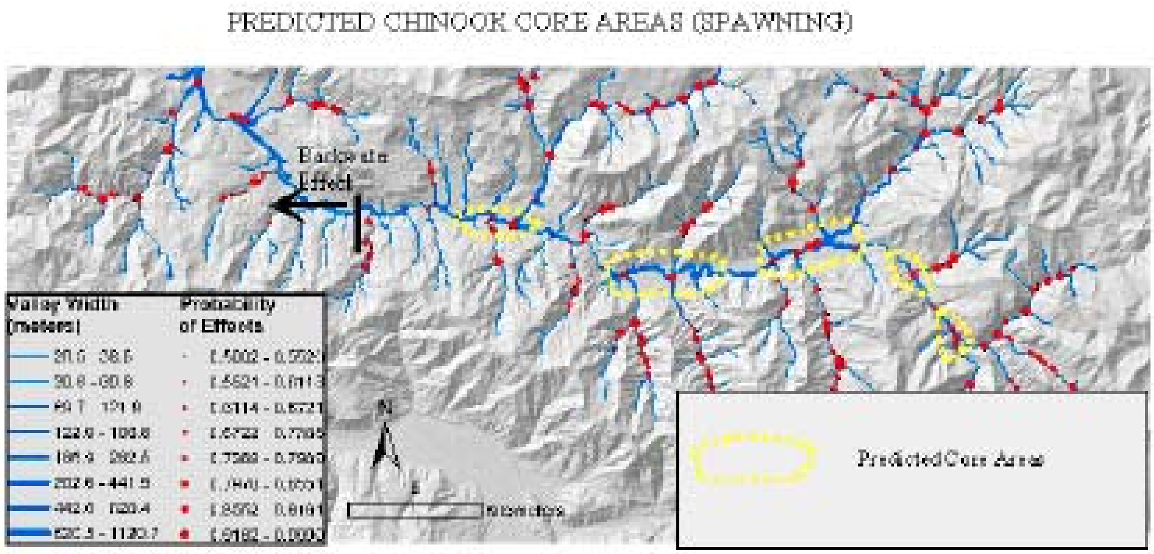

Figure 14. Predicted chinook core areas (From Martin et al. 2004)

Data gaps for current channel conditions

Key data gaps that should be addressed in future work include:

Inventory stream habitat conditions of the mainstem Green River (RM 67.75 to 85) and lower portions of major tributaries, including the North Fork Green River, Smay Creek, and Sunday Creek. Data collected should include bankfull and floodprone width, wetted channel area by habitat type, LWD size and quantity, riparian vegetation classification, surface particle size analysis, and qualitative assessment of spawning and rearing habitat for spring and fall chinook salmon.

- Comprehensive surveys of current logging road conditions in order to assess sediment production, risk of catastrophic failure, and fish passage barriers.

- Analysis of the impact of road and railroad lines on stream channel conditions, including disconnect of mainstem channels from the floodplain and side channels and reduced ability of the channel to laterally migrate.
- A study of the processes that have historically affected riparian vegetation and large woody debris recruitment within the Upper Green River. Processes such as fire history regime and flooding are important in determining historical quantities and size of large woody debris, and these processes need to be considered in order to establish a target quantity of large woody debris.
- Assess riparian conditions for stream shading along the mainstem Green River and major tributaries.

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